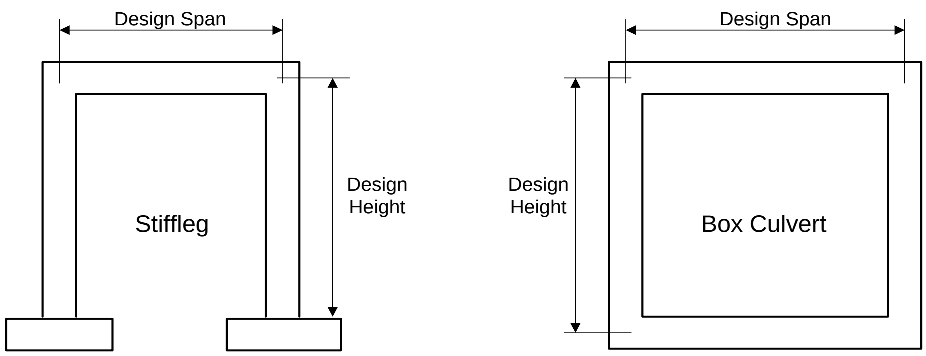
DESIGN GUIDELINES FOR CAST-IN-PLACE STIFFLEGS AND BOX CULVERTS

The design of concrete cast-in-place culverts shall be in accordance with the AASHTO LRFD Bridge Design Specifications as summarized in the following procedure.



Maximum Span for Stiffleg = 25 feet

Maximum Span for Box Culvert = 15 feet

When the maximum span for the structure type is exceeded, a different structure type or multiple cells should be evaluated.

Class 40 concrete and Grade 60 reinforcement should be used on all designs. Class 40B should be used for the footings or floors, barrel walls and wing walls. Class 40A should be used for deck slabs with less than 2’ of fill and Class 40B when the fill is 2’ or greater.

When the distance between the finished grade and the top of deck is less than 4” between the paved shoulders the concrete cover over the top layer of reinforcement should be 2½” and all reinforcement within 4” of the surface should be epoxy coated. When the fill is greater than 4” but less than 2’ the cover over the top layer of reinforcement should be 2½” however no epoxy steel is required. When the fill is 2’ or greater the cover should be 2” with no epoxy steel.

Main reinforcement for skews greater than 20° should be placed perpendicular to the centerline of the culvert. For skews 20° or less, the main reinforcement should be placed on the skew and the design span measured along the skew.

Fillets should have a minimum leg of 6”.

Walls should be double reinforced and have a minimum thickness of 10”.

Slab thickness shall be a minimum of 8” or (S +10)/30 whichever is greater (Table 2.5.2.6.3-1). The span length to determine the minimum thickness is the distance between centerline of walls. This is a little more conservative than the LRFD Specification requirement of using the clear span, but should only be a maximum of ½” more.

Construction joints with keyways should be placed transverse to the barrel and should be located in the walls, top slab, and bottom slab. Joint spacing should not exceed 40’. In lieu of a construction joint in the walls, the contractor may substitute an approved contraction joint.

The minimum footing width for stifflegs should be 2’ on rock and 3’ on other materials.

The design of culverts should meet the criteria for **Strength - 1** and **Service - 1** limit states.

Design Loads and Factors

(Table 3.4.1-1 & 2)	Strength – 1 Max. Factor	Strength – 1 Min. Factor	Service – 1 Factor
Concrete Member D.L.	1.25	0.9	1.0
Wearing Surface	1.50	0.0	1.0
Earth Fill D.L.	1.30	0.9	1.0
Earth Pressure (at rest, for barrel)	1.35	0.5 (Art. 3.11.7)	1.0
Earth Pressure (active, for wings)	1.50	0.9	1.0
Earth Surcharge (at rest, for barrel)	1.50	0.5 (Art. 3.11.7)	1.0
Earth Surcharge (active, for wings)	1.50	0.75	1.0
Live Load Surcharge	1.75	0.0	1.0
Live Loads	1.75	0.0	1.0
Water Pressure	1.00	0.0	1.0

Concrete D.L. Assume 150 lbs/ft^3 (Table 3.5.1-1).

Wearing Surface Assume a future overlay of 6" with a weight of 140 lbs/ft^3 (Table 3.5.1-1 & C3.5.1).

Earth Fill D.L. Use the density given in the Phase IV report. When not given assume 140 lbs/ft^3 (rolled gravel from table 3.5.1-1). The earth loads should be modified to account for soil-structure interaction. The soil-structure interaction factor is as follows (Art. 12.11.2.2):

For embankment installations (the typical case),

$F_e = 1 + 0.2(H/B_c)$ F_e shall not exceed 1.15 for installations with compacted fill along the sides of the box section, or 1.40 otherwise.

Where, H = fill height above the deck surface
B_c = out-to-out dimension of the culvert span

For trench installations,

$F_t = C_b B_d^2/HB_c$ Where, C_b = coefficient from figure 12.11.2.2.1-3
B_d = horizontal width of trench

Earth Pressure Shall be assumed to be linearly proportional to the depth of the soil based on the at rest pressure coefficient taken as $k_o = 1 - \sin \varphi_f$ where φ_f is the internal friction angle of the soil (Art. 3.11.5.2).

Earth Surcharge When the structure is buried the fill above the deck is considered an earth surcharge and a constant uniform horizontal earth pressure shall be applied in addition to the basic earth pressure. The uniform horizontal pressure due to earth surcharge should be based on the at rest coefficient k_o (Art. 3.11.6.1).

Live Load Surcharge At the barrel wall live load surcharge shall be determined as follows (based on table 3.11.6.4-1):

Up to 5' H:	$h_{eq} = 4.0'$
From 5' to 10' H:	$h_{eq} = 4' - 0.2(H-5')$
From 10' to 20' H:	$h_{eq} = 3' - 0.1(H-10')$
Higher than 20' H:	$h_{eq} = 2.0'$

Where h_{eq} is the equivalent height of soil in feet and H is the distance between the surface and the bottom of the footing in feet.

Live Loads The live loads shall be either a design truck in combination with a lane load or the design tandem in combination with a lane load (Art. 3.6.1.2). Impact shall be $0.33(1.0 - 0.125D_E)$ but shall not be less than 0.0 where D_E is the minimum depth of earth cover over the structure (Art. 3.6.2.2). Impact shall only be applied to the truck or tandem (Art. 3.6.2.1).

Fill less than 2' and the clear span greater than 15 feet:

The lateral distribution for the top slab shall be based on the equivalent strip method (Art. 4.6.2.3) as follows:

$E = 10 + 5(L_1 W_1)^{0.5}$ for single lane loaded, or

$E = 84 + 1.44(L_1W_1)^{0.5} \leq 12W/N_L$ for more than one lane loaded

Where E = lateral distribution width (inches), the smaller value shall be used
L_1 = the clear span length (ft)
W_1 = the lesser of the edge-to-edge width or 30 feet for one lane loaded or 60 feet for two or more lanes loaded (ft)
W = the actual edge-to-edge width of the bridge (ft)
N_L = the number of design lanes on the bridge

The equivalent strip width used for the top slab should also be used for the walls and floor (Art. 12.11.2.3). Slab designs based on the equivalent strip method are considered adequate for shear (Art. 5.14.4.1). Multiple presence factors should not be used with the equivalent strip method.

<u>Fill less than 2’ and clear span less than or equal to 15’:</u>

The lateral distribution shall be based on the equivalent strips given in Table 4.6.2.1.3-1 (Art. 4.6.2.1.3) as follows:

$E = 26.0 + 6.6(S)$ for positive moments

$E = 48.0 + 3.0(S)$ for negative moments

Where E = lateral distribution width (inches)
S = span length, center-of-support to center-of-support (ft)

The equivalent strip width used for negative moments in the top slab should be used for the walls and floor (Art. 12.11.2.3). Slab designs based on the equivalent strip method are considered adequate for shear (Art. 5.14.4.1). Multiple presence factors should not be used with the equivalent strip method.

<u>Fill greater than 2’ all span lengths:</u>

Wheel loads may be considered to be uniformly distributed over a rectangular area with sides equal to the dimension of the tire contact area increased by 1.15 times the depth of fill in granular backfill, or the depth of fill in all other cases. The lane load may be distributed over 12 feet in all cases. The tire contact area is 20 inches wide and 10 inches long. Where such areas overlap the total load shall be uniformly distributed over the area within the resultant perimeter. Multiple presence factors shall be used where applicable. Live load may be neglected where the depth of fill is over 8 feet and exceeds the total length of the structure. Where the live load moment, based on distribution through fills, exceeds the moment calculated by the equivalent strip method the equivalent strip method should be used. (Art. 3.6.1.2.6)

Shear design when fill is greater than 2’ (Art. 5.14.5.3): $\phi V_c > V_u$ $\phi = 0.9$

$V_c = [0.0676(f_c`)^{0.5} + 4.6(A_s/bd_e)(V_ud_e/M_u)]bd_e$ (in kips)

But V_c shall not exceed $0.126(f_c`)^{0.5}(bd_e)$

where: A_s = area of steel (in^2)
d_e = effective depth from extreme compression to tension centroid (in)
V_u = shear from factored loads (kips)
M_u = moment from factored loads occurring simultaneously with V_u (kip-in)
b = design width (in)

For single cell boxes only, V_c need not be less than $0.0948(f_c`)^{0.5}(bd_e)$

<u>Water Pressure</u> Culverts should be designed assuming static water pressure on the inside of the walls for the full design height.

Analysis The analysis should be based on the equivalent strip method assuming a rigid frame fixed against lateral movement at the base and free to side-sway at the top (classical force and displacement method). The design span length and wall height should be based on the centerline-of-member to centerline-of-member dimensions.

For simplification in determining the shears and moments in the structure the foundation soil pressure on box culverts may be considered to be uniformly distributed across the floor for all load cases (ITD Bridge Section policy).

Where monolithic haunches inclined at 45° are used the negative reinforcement in the walls and slabs may be proportioned based on the flexural moment at the intersection of the haunch and uniform depth member (Art. 12.11.4.2).

Reinforcement

Minimum Reinforcement (Art. 5.7.3.3.2); Min A_s shall be sufficient to resist $1.2M_{cr}$ or $1.33M_u$ whichever is less

Maximum Reinforcement (Art. 5.7.3.3.1); Max $A_s = 0.357\beta(f_c`/f_y)bd$ $\beta = 0.85$ for 4 ksi concrete

Equation derived from $c/d_e \leq 0.42$

Transverse Distribution Reinforcement; (Art. 5.14.4.1) $A_{dist} = A_s/(L)^{0.5}$ but no more than $0.5A_s$

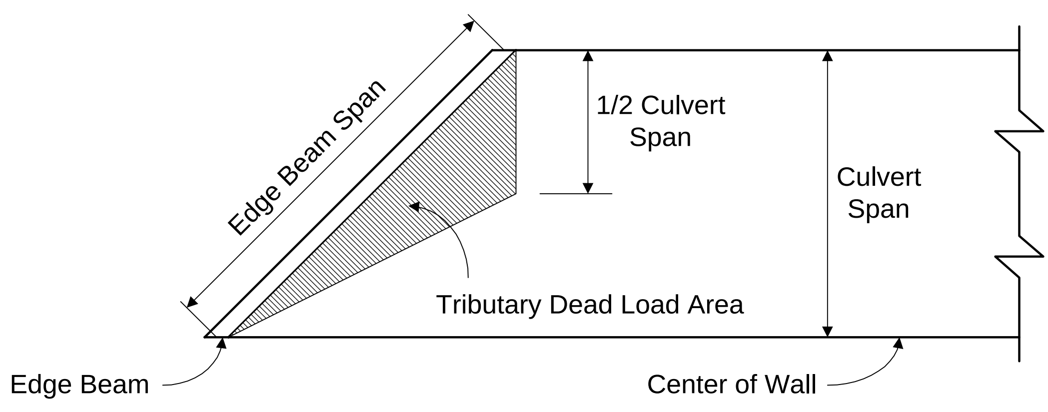
where A_s is the required positive moment reinforcement and L is the span length in feet

For crack control (Art. 5.7.3.4); $Z = 155/(1+d_c/0.7d)$ to be used in equation 5.7.3.4-1

where d_c is from center of bar to the tension face in inches

Note: When calculating the Service-1 limit state stresses in the reinforcement for the purpose of satisfying crack control requirements the compression thrust forces in the culvert members may be considered in order to take advantage of the resulting reduction in tensile stresses. The equations presented in the commentary for Article 12.11.3 may be used for this purpose.

Edge Beam Design The Live Load on edge beams shall be one line of wheels (either truck or tandem) plus a tributary portion of the lane load (Art. 4.6.2.1.4a). The tributary portion of the lane load shall be considered to be a uniform load of 64 lbs/ft^2 on either the effective edge beam width, or in the case where the edge beam is skewed relative to the main slab reinforcement, on the same tributary area as defined for dead load. The effective edge beam width for culverts with main slab reinforcement parallel with the edge beam shall be the distance between the edge of deck and the inside face of the barrier or curb, plus 12”, plus one-half of the strip width, E, determined above. The effective width shall not exceed either the full strip width or 72” (Art. 4.6.2.1.4b). The dead load should be the weight of all structure components and the fill on the effective width. When the end of the culvert is skewed relative to the main slab reinforcement the dead load applied to the edge beam shall also include the weight of all loads on the tributary area at the end of the culvert as shown below. These loads may be applied to the edge beam as a uniform load. The edge beam should be designed as a simple span with a span length based on center-of-wall to center-of-wall along the skew.



Footing Pressures The dead load footing pressures on the footings of stifflegs and the floor of box culverts may be uniformly distributed to the total footing area. The live load footing pressures may be assumed to act on a length of footing equal to the width of the design lane plus 1.15 times the distance from the surface to the bottom of the footing (this is the same distribution rate as the live load on the fill over a buried structure). Overlapping areas from more than one lane loaded shall be uniformly distributed over the length of the overlapping regions, multiple presence factors shall be applied where applicable. The total design loaded length shall not exceed the actual footing length. The footing pressure should be assumed to be uniform across the width of the footing or floor. Foundation design shall be in accordance with Section 10 of the LRFD Code.

Wing Wall Design

Live load surcharge shall be applied where vehicular load is expected to act on the surface of the backfill within a distance equal to one-half the wall height behind the back face of the wall. H_{eq}, the equivalent height of soil in feet, should be based on Table 3.11.6.4-2.

The typical wing wall on a spread footing is free to deflect at the top under soil pressure and may therefore be designed using soil pressures based on the active state. The soil pressure coefficient, k_a, may be determined by the Coulomb method from the information in the Phase IV report.

Overturning:

For foundations on soil, the location of the resultant of the factored strength-1 and extreme event-2 (vehicle collision at rail, if present) the reaction forces shall be within the middle one-half of the base. On rock the resultant shall be within the middle three-fourths (Art. 11.6.3.3).

Sliding:

For footings on cohesionless soils the factored resistance against failure by sliding may be taken as (Art. 10.6.3.3):

$Q_R = \varphi_T(V \tan \varphi_f)$ where:

Q_R = factored resistance
φ_T = 0.8 for strength-1 (from table 10.5.5-1)
φ_T = 1.0 for extreme event-2 (Art. 11.6.5)
V = total factored vertical load (minimum factors)
φ_f = internal friction angle of soil

The factored (strength-1 and extreme event-2) lateral loads shall not exceed Q_R .

Wing Wall Footings:

Foundation design shall be in accordance with Section 10 of the LRFD Code.

Revisions:

June 2000 – Stiffleg and Box Culvert Design Guidelines established based on LRFD specifications and previous Bridge Section Policy.

May 2003 – The live load distribution for spans 15’ or less was revised to reflect changes in AASHTO Article 4.6.2.1.3. The location of the resultant soil pressure at 0.4 H for wing walls was deleted to reflect changes in AASHTO Article 3.11.5.1.

June 2004 – The definition of span length for determining equivalent strip width was changed to be consistent with the design span. The edge beam loading was clarified.